Integrating a 2-D hydrodynamic model into the Landlab modeling framework

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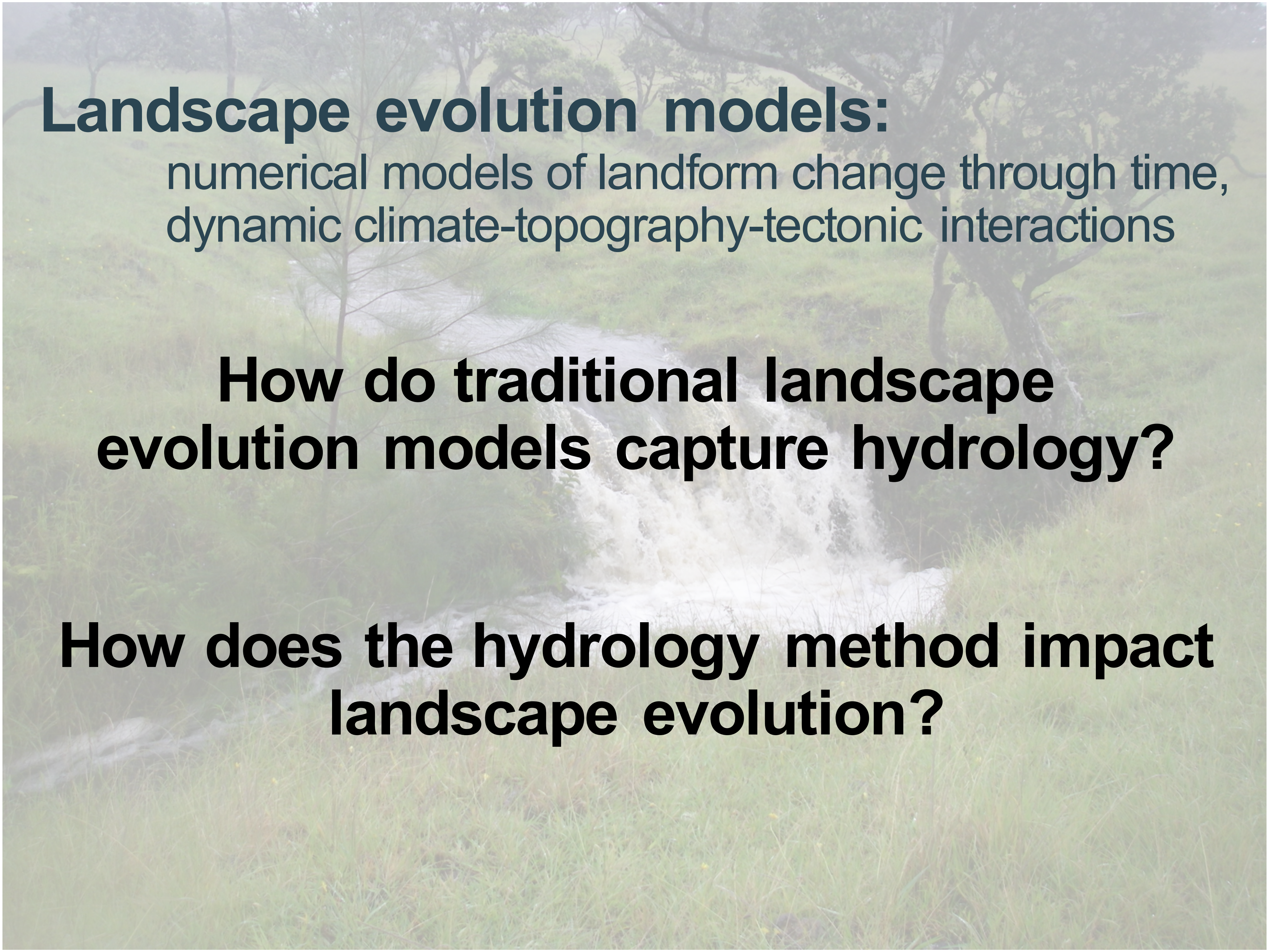


Landscape evolution models:

numerical models of landform change through time,
dynamic climate-topography-tectonic interactions

How do traditional landscape evolution models capture hydrology?

How does the hydrology method impact landscape evolution?

Steady-state hydrology

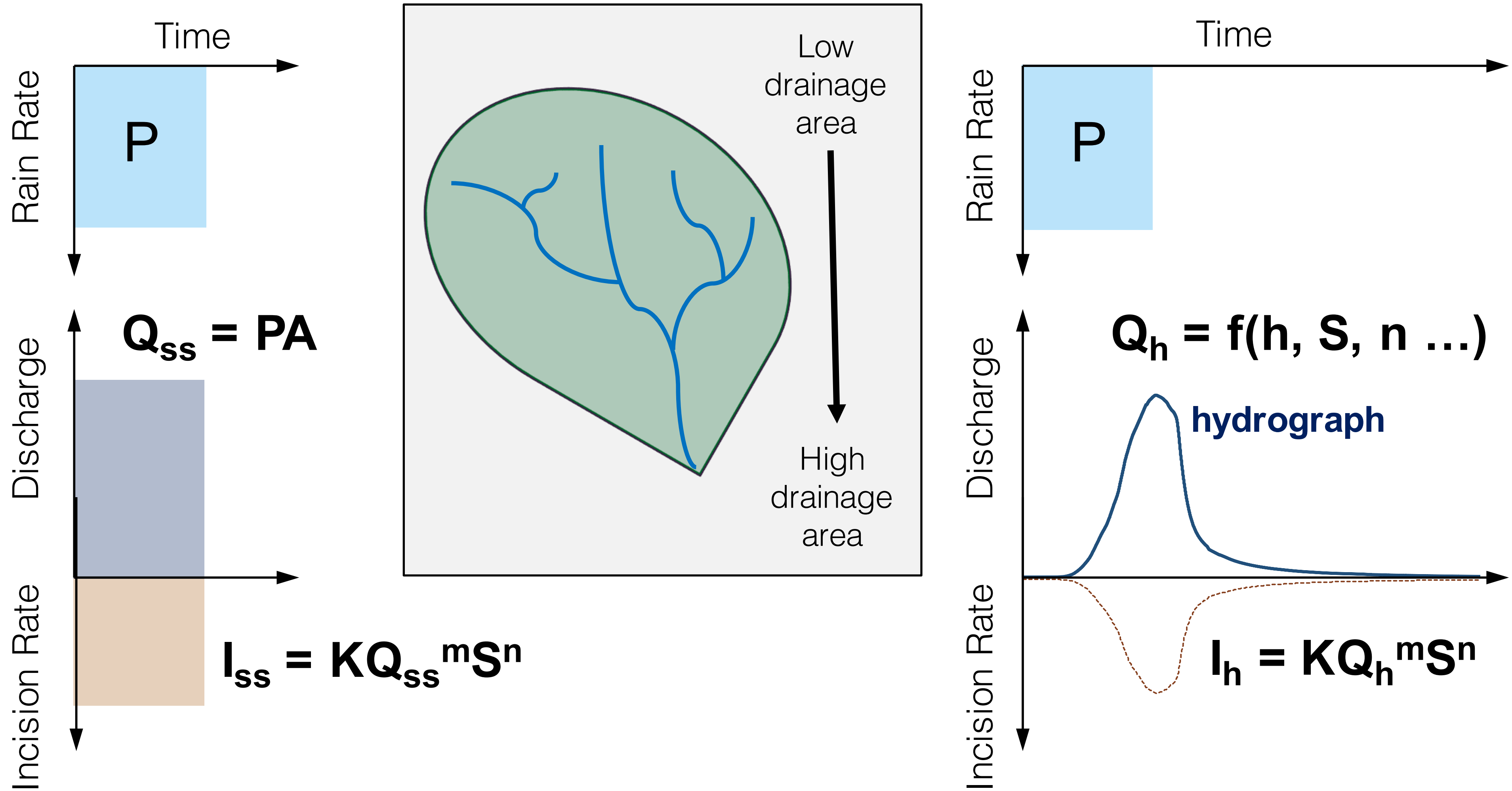
Each event:

- single rainfall rate
- single discharge at all points in watershed
- single incision rate

Nonsteady hydrology

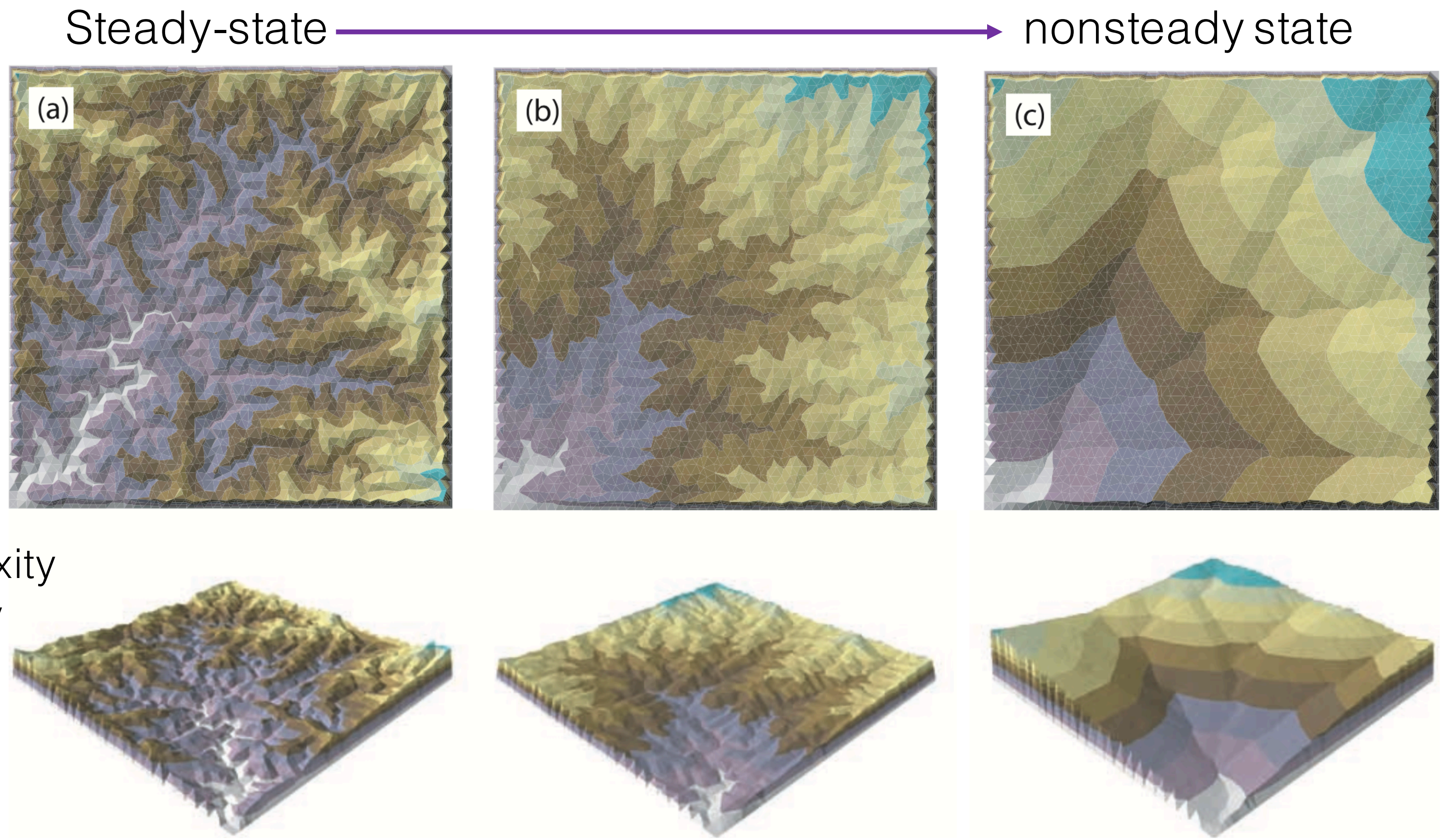
Each event:

- single rainfall rate
- wave propagates across watershed:
  - nonsteady discharge at each point
  - nonsteady incision at each point



Steady-state assumption can be problematic:

large catchments and short-duration precipitation events



Note:

- greater relief
- increasing convexity
- low valley density

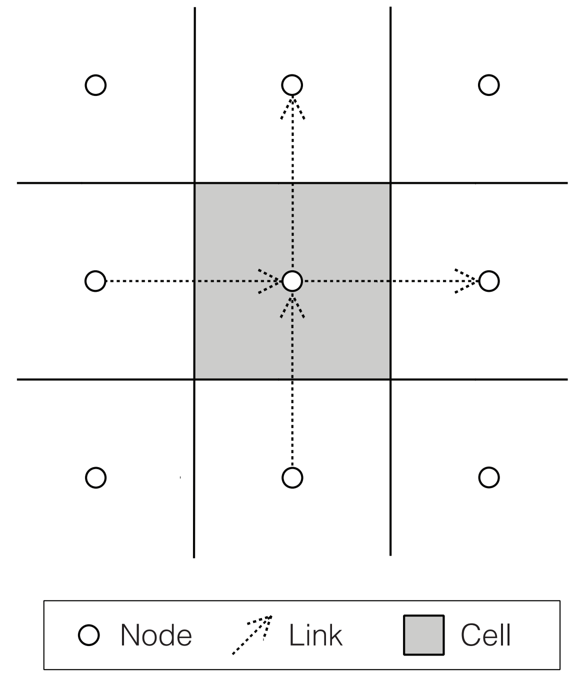
Sólyom and Tucker, 2004, *Journal of Geophysical Research*

Landlab: *A Python toolkit for modeling Earth surface processes*

- Open-source modeling library
  - 2-D gridding libraries
  - Pre-built process components
  - Coupling framework: multi-process models
  - Input / output utilities

Geared toward (but not limited to!) Earth-surface dynamics

Raster grid



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GitHub

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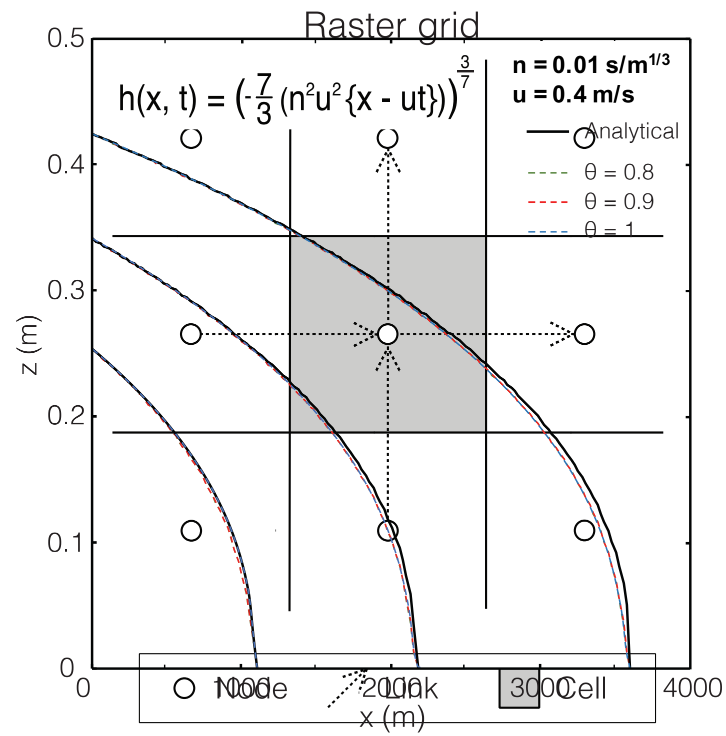
de Almeida overland flow component

- Urban flood inundation model (de Almeida et al., 2012)
- Centered finite-difference, explicit
- Routes hydrograph at all grid locations, flow in D4



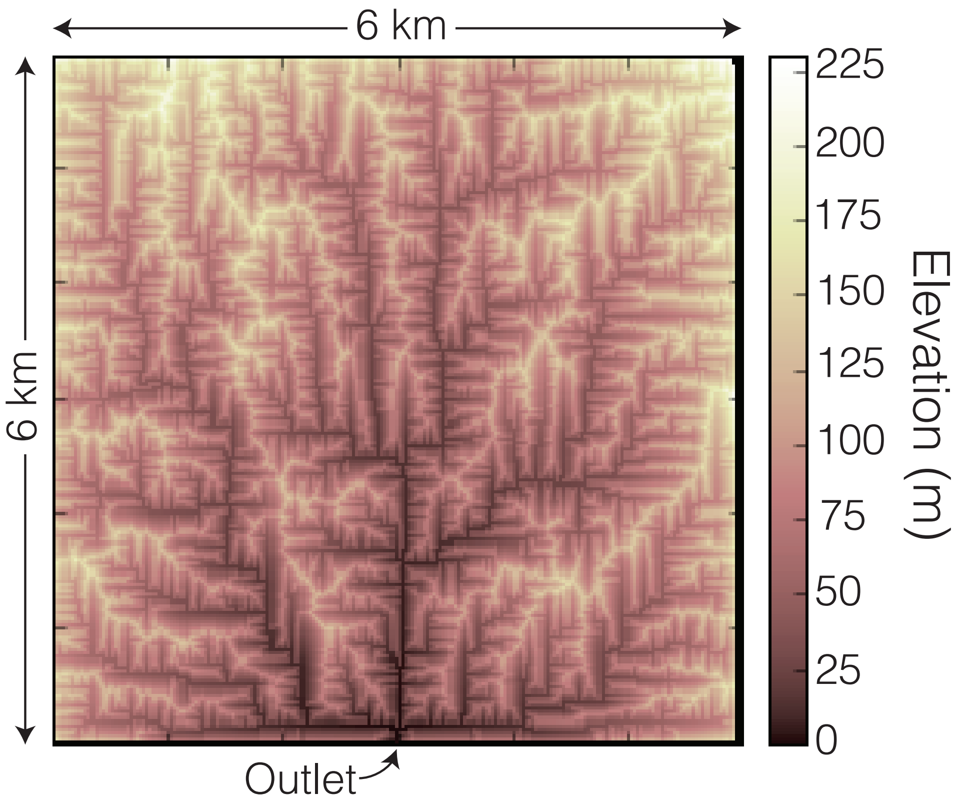
$$q_{t+1} = \frac{\left[\theta q_t + \frac{1-\theta}{2}(q_{t,\,left} + q_{t,\,right})\right] - gh\Delta t S_w}{1 + g\Delta t n^2 \left|q_t\right| / h^{7/3}}$$

de Almeida et al., 2012, WRR

$$\Delta t = \alpha \frac{\Delta x}{\sqrt{gh_f}}$$

Hunter et al., 2005, Advances in Water Resources

Model domain



Geomorphic steady-state topography

(uplift == erosion rate)

36 km^2 drainage area

Grid resolution: 30 m x 30 m

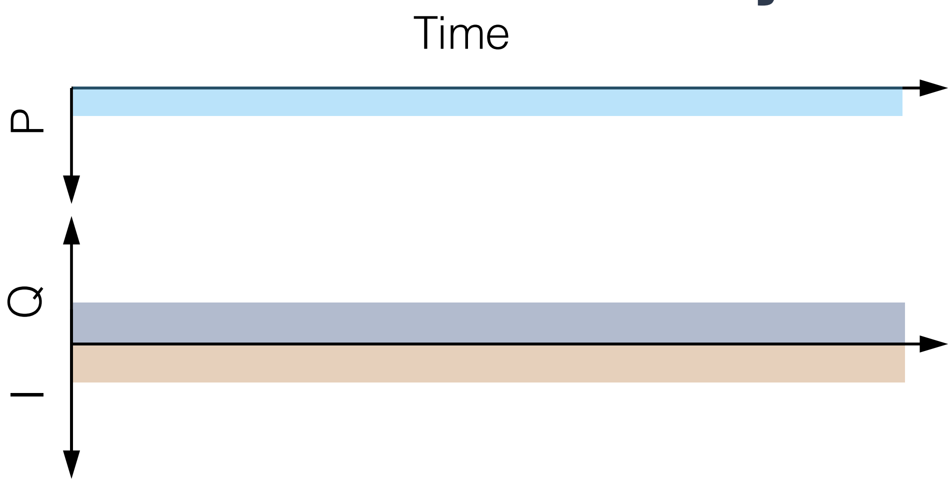
Slopes: ~10^{-1} to ~10^{-2}

Simple stream power parameters

$$I = KQ^mS^n$$

Parameter	Value
K (*erodibility*)	0.0007 m/yr
m	0.5
n	1.0

Steady-State Parameters

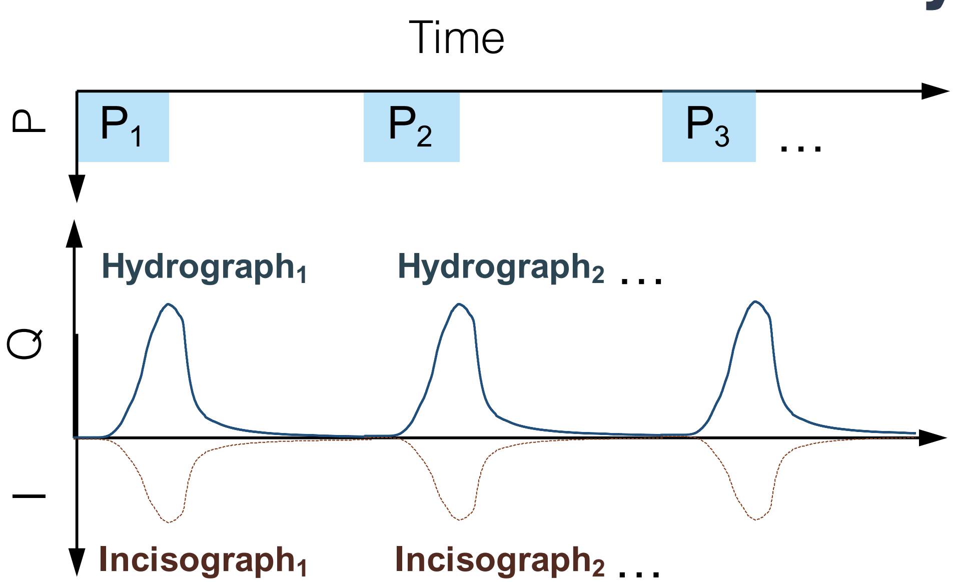


Rainfall characteristics

0.5 m/yr total rainfall for **10 years**

Low, constant rainfall rate

Nonsteady Parameters

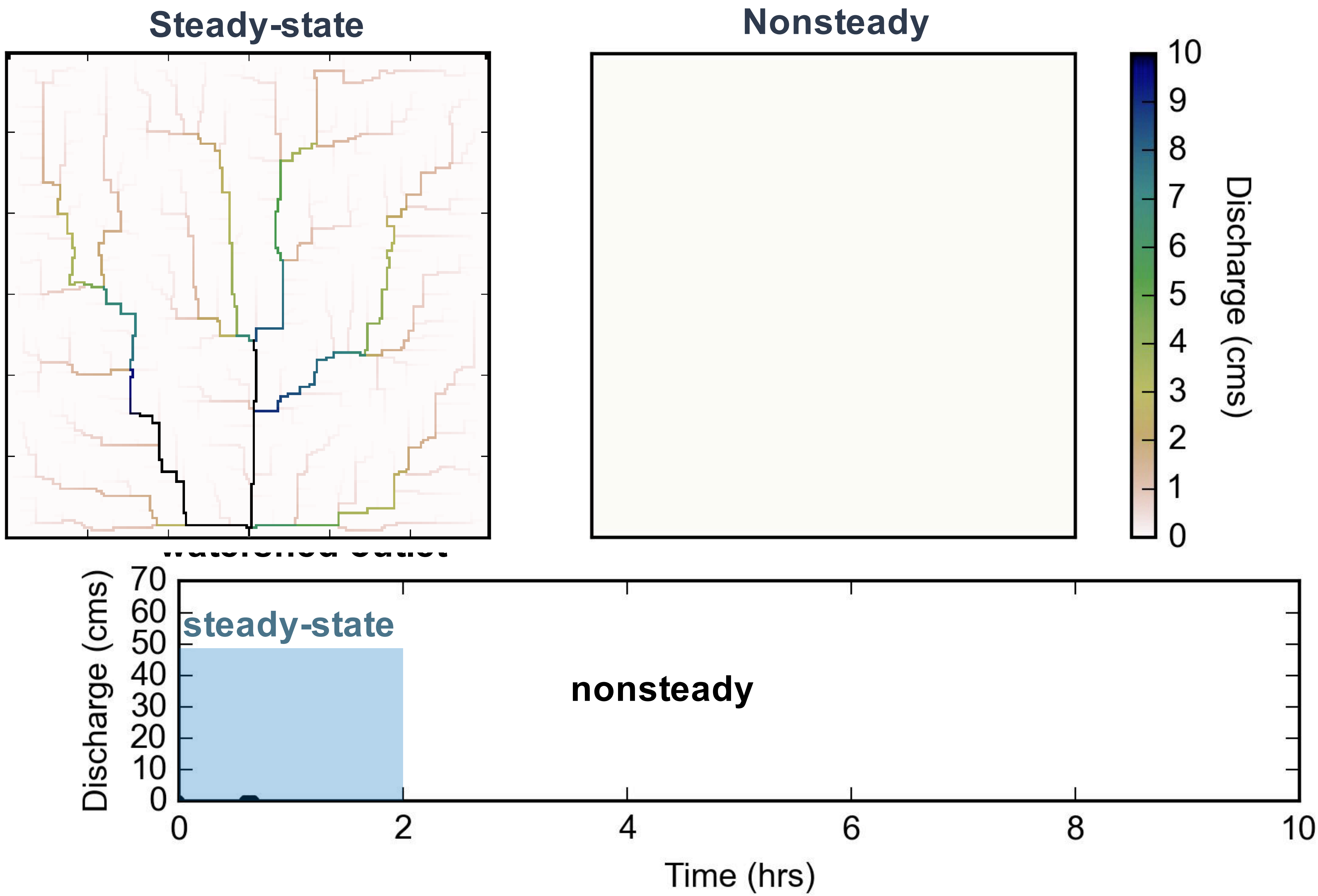


500 hydrograph events

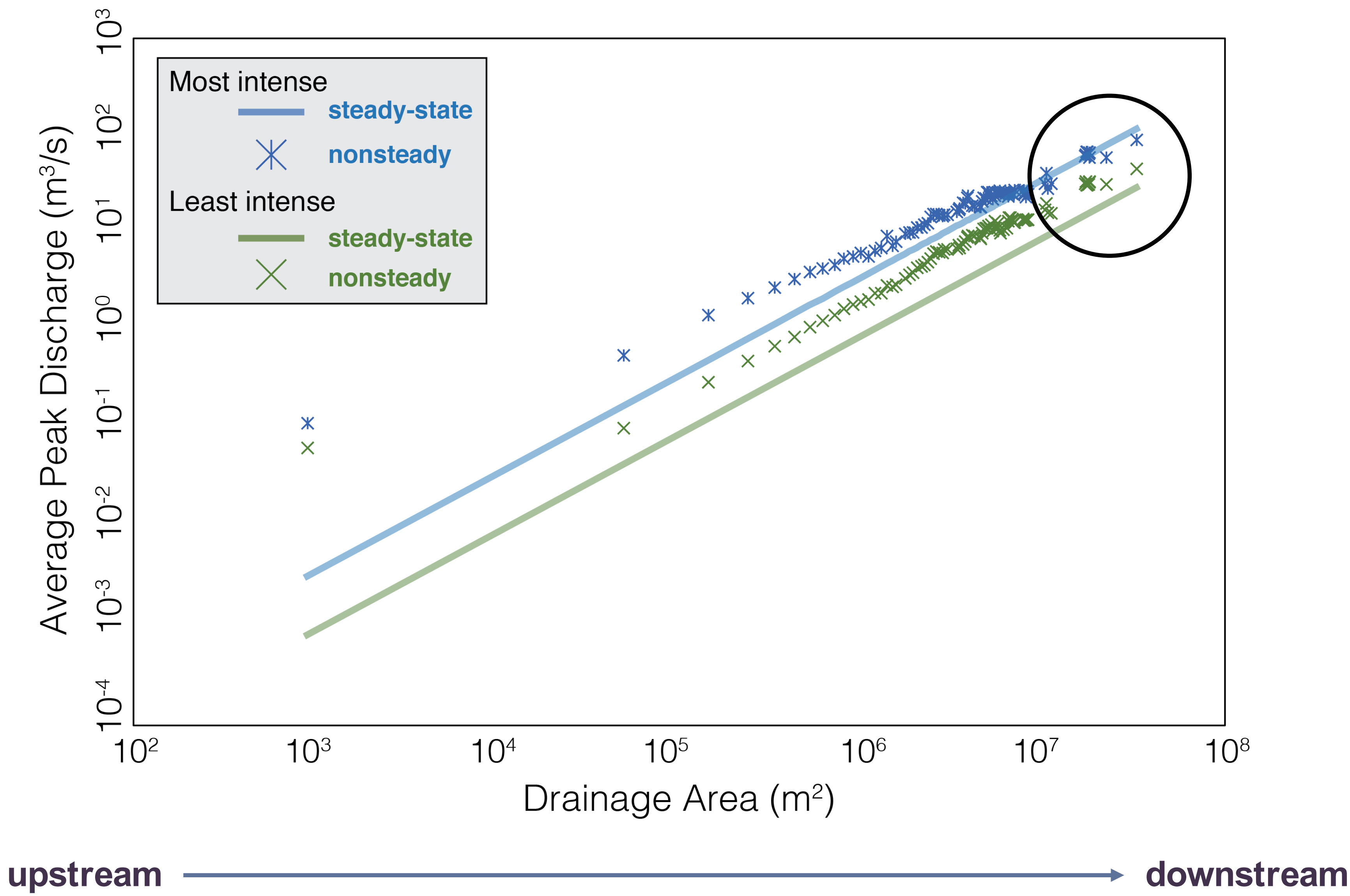
3 different storm types:

Intensity	Duration
2.5 mm/hr	4 hr
5 mm/hr	2 hr
10 mm/hr	1 hr

Intensity

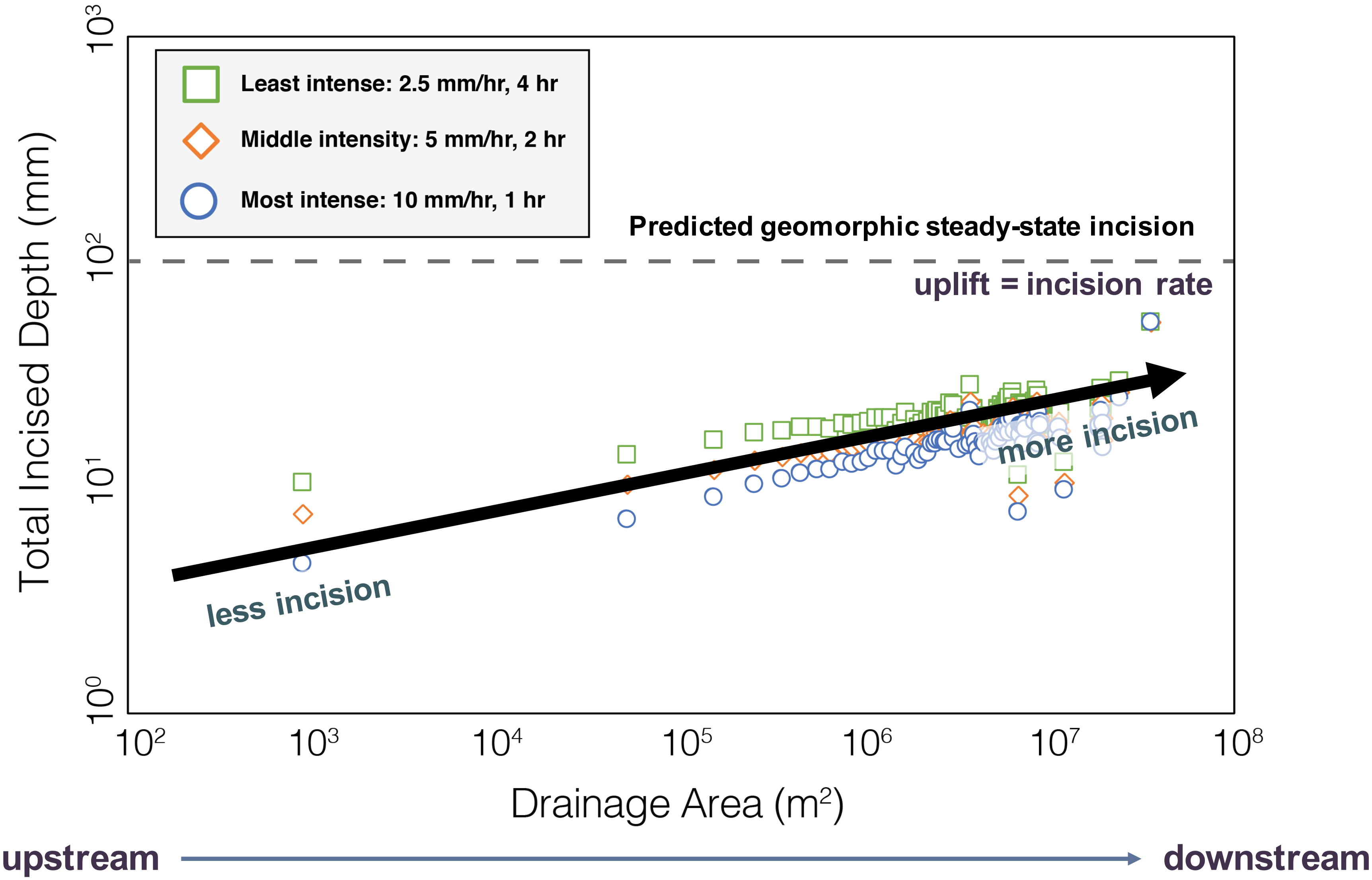

Steady-state
Nonsteady
10
9
8
7
6
5
4
3
2
1
0
Discharge (cms)
70
60
50
40
30
20
10
0
Discharge (cms)
steady-state
nonsteady
0
2
4
6
8
10
Time (hrs)

Average peak discharge is greater than predicted steady-state in upstream



Cumulative incised depth by nonsteady method less than predicted by the steady-state hydrology model

In all intensities, higher drainage areas experience greater incision



Peak discharge in nonsteady methods can exceed predicted steady-state: impact on incision?

Implications for landscape evolution modeling:

Incision in nonsteady cases less than steady-state:

- Higher incision downstream implies greater relief in modeled landscapes
- Potential for increases in channel concavities

Are we capturing short-term events with steady-state?

- Predictive models: post-fire events

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CSDMS
COMMUNITY SURFACE DYNAMICS MODELING SYSTEM

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